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Training Manual for Uranium Mill Workers on Health Protection from Uranium

ORIGINAL

U.S. Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

N. McElroy, A. Brodsky

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N. McElroy, A. Brodsky

Division of Radiation Programs and Earth Sciences
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

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PREFACE

The milling of uranium is regulated for radiation safety purposes by the U.S. Nuclear Regulatory Commission (NRC) or, in several States, by the individual States themselves. The Mine Safety and Health Administration (MSHA) regulates mills for industrial safety. NRC regulations require that all persons who work in or frequent an area where there is radioactive material receive radiation safety training.

This manual provides the general information on radioactive material safety that the NRC requires an employer to tell such persons, but it is not intended for self-instruction. The information should be taught by a qualified instructor using about two to four hours of classroom time. Time should be available for questions, answers, and classroom discussion. The appendixes contain additional information that may be of interest to some workers.

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The authors are grateful to Dr. Stephen A. McGuire and Carol A. Peabody for Figures 2, 3, 4, 5, 6, 7, and 8, which were taken from their training manual, NUREG/BR-0024, "Working Safely in Gamma Radiography" (U. S. Nuclear Regulatory Commission, Washington, DC 20555, September 1982).

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INTRODUCTION

If you work around uranium, you may be exposed to low levels of radiation. If you take excessive amounts of uranium into your body, the chemical action of uranium may cause kidney damage. However, if your exposure to uranium and radiation is less than the maximum amounts permitted by the regulations of the Nuclear Regulatory Commission, it is very unlikely that your health will be affected.

The purpose of this manual is to provide you information that will help reduce your exposure to uranium. It is intended for use in the radiation safety training that the regulations require your employer to provide to anyone who may frequent an area where there is radioactive material such as uranium.

In addition, the regulations require your employer to make every reasonable effort to keep radiation exposures as low as reasonably achievable (ALARA), taking into account the available technology and the cost of improvements in relation to their safety benefit. The ALARA philosophy can be successful only if each individual worker makes an effort to keep his or her radiation exposure as low as possible. You can make ALARA work by following the procedures that have been established, asking questions if you don't understand the procedures, and telling your managers about problems and safety hazards that they may not know about.

This manual does not cover your company's specific procedures. You should study your company's procedures for the operation, inspection, and maintenance of equipment; the specific requirements in your company's license; and your company's chemical, mechanical, fire, safety, and emergency procedures. Your instructor should demonstrate your company's procedures and the use of the equipment used at your mill.

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CHAPTER 1. WHY IS RADIATION SAFETY TRAINING IMPORTANT?

Radiation safety training is important because there are several hazards to your health around a uranium mill. Training can help you recognize these hazards and help you avoid them, or at least help you minimize the hazards to your health.

Uranium and the other radioactive materials that are found with uranium give off low levels of radiation that might cause a small increase in your chance of getting cancer. Uranium can cause severe kidney damage if too much uranium dust is regularly inhaled, swallowed, or absorbed through the skin. For these reasons, the NRC requires that your employer provide radiation safety training for workers.

URANIUM IN YOUR BODY

When uranium dust is inhaled, some of it is deposited on the lung tissue. Your body's dust-clearing mechanisms transfer many of the dust particles out of the lungs. However, some dust remains until it is dissolved in the lung fluids. If a large amount of uranium dust were in the lungs for a long time, the radiation given off would increase the chance of lung cancer.

When uranium dissolves in the lung fluids, it enters the bloodstream; most of it is quickly filtered out by the kidneys and then is gradually released in the urine. The rest of the uranium in the bloodstream is deposited primarily in the kidney and bone tissues. If too much uranium is taken up by the kidneys at one time, it could cause kidney damage because of its chemical action on the kidney tissues. See Figure 1.

Hazards to Your Lungs

Lung cancer in ore miners and millers has been studied for many years. Lung cancer was first associated with mining by European doctors in the early sixteenth century. The cancer was probably caused by high radon gas and ore dust levels. Emphysema and pneumoconiosis are other lung diseases that have been associated with mining and milling work.

Fortunately, lung disease levels in ore workers are much lower today because of improved work methods and better ventilation.

Uranium in Your Kidneys

Studies have determined that soluble uranium enters the bloodstream and is then filtered out by the kidneys. If uranium is deposited in the kidneys in excessive amounts, the chemical action of the uranium can destroy the filters in the kidneys. When this happens, important chemicals in the blood are lost into the urine.

RADIATION EFFECTS

Scientists have known for a long time that exposure to large amounts of radiation can have harmful effects in humans. Some of the harmful effects you may have heard of are radiation burns, cancer, and genetic defects in future generations. These are discussed below.

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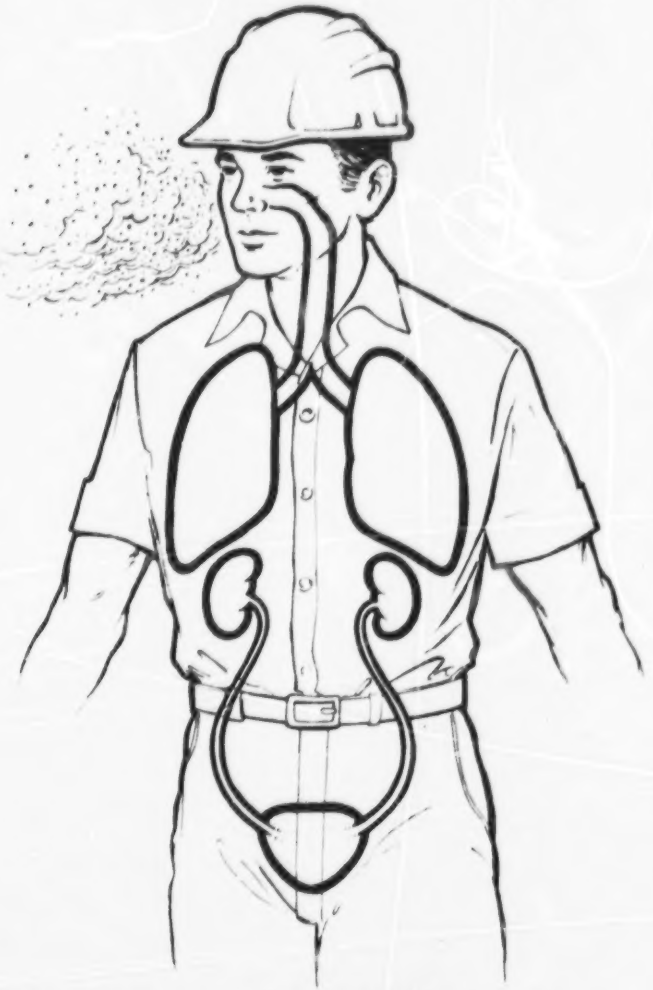
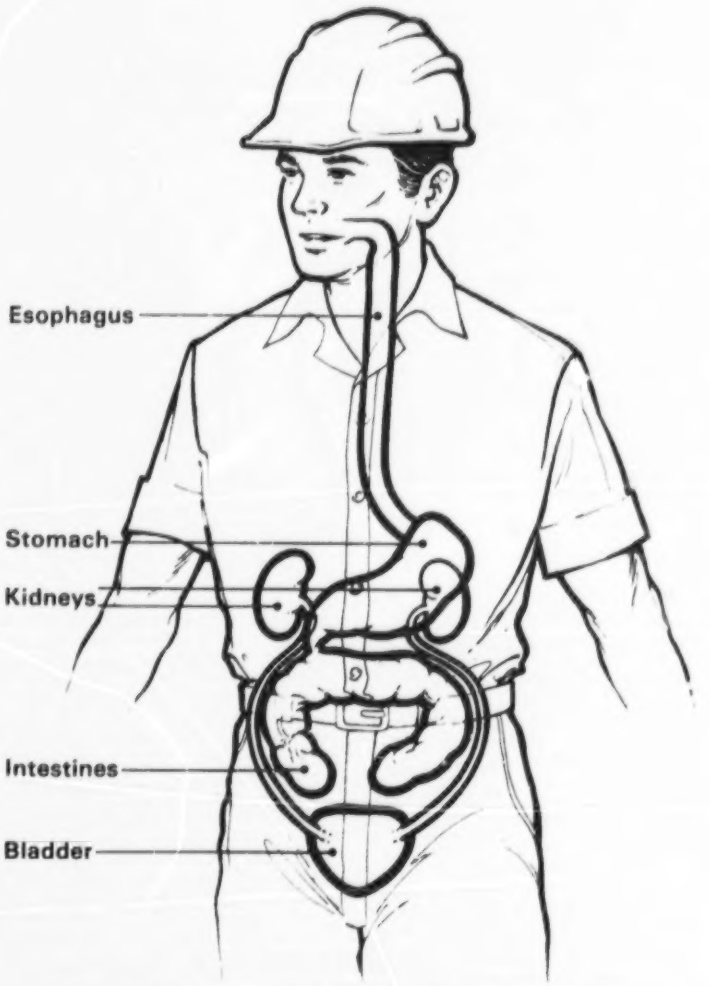


a. Uranium dust that is inhaled goes to the lungs. If it is insoluble, it stays there until the dust clearing mechanism carries it back out. If it is soluble, it enters the bloodstream. Most of it is filtered out by the kidneys, and then is excreted in the urine.



b. Uranium dust that is swallowed goes to the stomach. If it is insoluble, it travels through the digestive tract. If it is soluble, it enters the bloodstream and is filtered out by the kidneys. Then it is excreted in the urine.

Figure 1 - Routes of entry of uranium into the body.

Skin Burns

Very high doses of radiation can cause skin burns. Some early experimenters who worked with high concentrations of natural radioactivity suffered burns caused by radiation. Fortunately, the radioactive material in mills is not concentrated nearly enough to cause radiation burns. A dose of about 600,000 millirems in a few days would be needed to cause temporary skin reddening and irritation. The average dose to the whole body of a mill worker for a whole year is only 270 millirems.

Increase in Chance of Getting Cancer

Radiation can have effects that are not seen for a long time. For example, excessive exposure to radiation can cause cancer that does not appear until many years after the exposure. However, the chance of getting cancer from radiation is extremely low when your radiation dose is within the legal limits. The lower the dose, the smaller the chance. Agencies that regulate radiation exposure assume, for the sake of prudence, that even low doses of radiation can increase your chance of getting cancer, so workers are urged to keep their own doses as low as they can.

Although only a small portion of all Americans are exposed to radiation at work, about one-fifth of all the deaths in the United States each year are caused by cancer (see Figure 2). A few of these cancers might be caused by radiation, but scientists believe that most cancers have other causes. If a person does get cancer, it is impossible to know whether the cancer was caused by exposure to radiation or whether the cancer would have occurred anyway from some other cause. Cancer caused by radiation cannot be distinguished from cancer caused by chemicals or viruses.

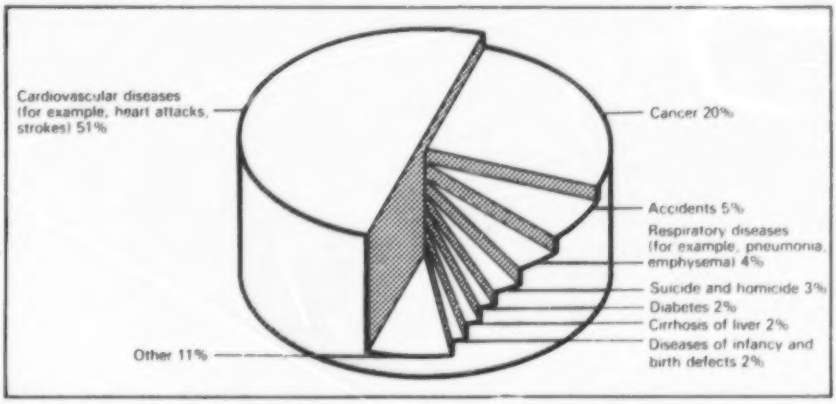

Cardiovascular diseases (for example, heart attacks, strokes) 51%
Cancer 20%
Accidents 5%
Respiratory diseases (for example, pneumonia, emphysema) 4%
Suicide and homicide 3%
Diabetes 2%
Cirrhosis of liver 2%
Diseases of infancy and birth defects 2%
Other 11%

Figure 2 - Relative chances of death from cancer and other causes

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Increase in Chance of Genetic Defects

Scientists have known since 1927 that radiation can cause genetic defects, which are changes in the cells from which future children may be created. The early evidence was obtained from experiments with insects. Increased numbers of genetic defects were found in the descendants of insects that had been exposed to radiation. The genetic defects were the same types that are found naturally. Radiation did not create giant insects or make them stronger than usual. Later experiments with animals had similar results.

Radiation exposure might increase the number of genetic defects that occur in humans. However, scientists have not seen any more genetic defects in the children of people who have been exposed to the amounts of radiation that you get at work than in children of people who have not been exposed.

Uncertainty

Scientists who are trying to determine the effects of low-level radiation say that their estimates of its effects are uncertain. They say this because the effects of doses of radiation below legal limits are too small to be measured directly. One reason for this is that cancers caused by radiation cannot be distinguished from cancers resulting from other causes. Another reason is that the cancer rate also depends on sex, age, lifestyle, race, and other unknown factors. All these variables add uncertainty to any estimate of the expected number of cancers in a particular group of people.

Sometimes the reasons for different cancer rates are partially understood. For example, more lung cancer is usually observed in groups of people who smoke cigarettes. But often the reasons for the differences in cancer rates are not well understood. These differences make it difficult to compare the differences in cancer rates between people exposed to radiation and people not exposed to radiation. Even though scientists have gone to great effort to detect radiation effects, they have not been able to identify any effects caused by the amount of radiation exposure permitted by the regulations.

Therefore, we can say with certainty that radiation doses that are within legal limits cause only a tiny fraction of all the cancers and genetic defects in the U.S. population. There is some uncertainty in precisely how small the fraction is. There is almost no uncertainty that the risks from radiation doses within the legal limits are smaller than many other risks we commonly encounter and accept in our lives.

Figure 3 shows how small radiation risks from a maximum dose of 20 rems are compared to other familiar risks in our lives. Most uranium mill workers receive much less than 20 rems during their entire working lives.

SUMMARY

There may be a very small chance of getting cancer with any radiation dose, and there may be a chance that any uranium that gets into your body could cause some damage to your lungs or kidneys. However, if your radiation dose and uranium intake are kept below the maximum amount allowed by the regulations, your chance of contracting a lung or kidney disease, if any, will be very small compared to the health risks associated with many other events and activities encountered in normal day-to-day life.

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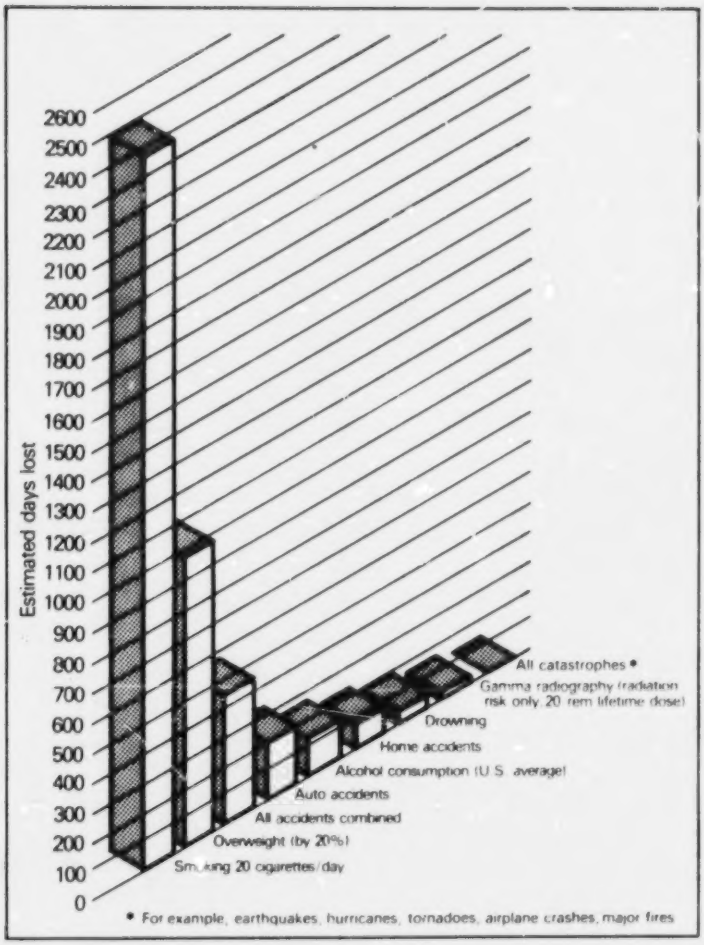

Figure 3 - Relative risks of everyday hazards that shorten life. The risk to uranium mill workers of working 20 years in a mill would be less than that shown above for radiographers. Most mill workers receive much less than 20 rems during their working lifetimes.

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CHAPTER 2. RADIOACTIVITY AND RADIATION

ATOMS

Atoms are the building blocks of nature that make up everything we can touch. Each atom has a heavy central core called the nucleus. The nucleus is simply a collection of two smaller kinds of particles, protons and neutrons. Each proton has a small positive electrical charge; neutrons are electrically neutral. Electrons are very light-weight particles that orbit around the nucleus. Each electron has a small negative electrical charge that is equal to a proton's positive charge. Normally, each atom has as many electrons orbiting the nucleus as it has protons in the nucleus. Therefore, individual atoms are electrically neutral. (See Figure 4.)

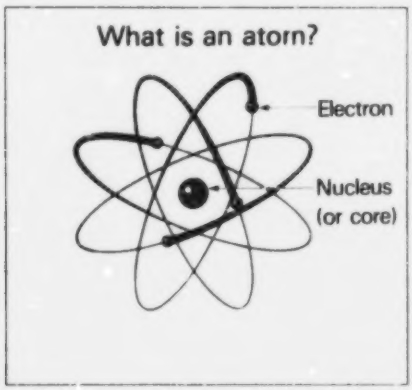

Figure 4 - Simplified diagram of an atom. The electrons revolve in outer shells. Their negative charges are balanced by the same number of positively charged protons in the nucleus of a particular type of atom.

There are 92 basic kinds of atoms, or elements, that occur in nature. For example, there are carbon atoms, oxygen atoms, hydrogen atoms, and uranium atoms (in addition to the 88 other elements). All carbon atoms behave alike chemically because they always have six protons in the nucleus and six orbiting electrons. However, some carbon atoms that occur in nature have six neutrons in the nucleus, some have seven, and some have eight. These are called isotopes of carbon. We can describe each isotope by adding the number of neutrons to the number of protons. Also, by using the abbreviation for the elements, a simple shorthand can be developed. For example, C-12 means a carbon atom with six protons and six neutrons in the nucleus.

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TYPES OF RADIOACTIVE DECAY

Beta

Carbon-14 is another isotope of carbon. It has six protons and eight neutrons in the nucleus. Although there is no difference between C-12 and C-14 atoms chemically, the nucleus of the C-14 atom is unstable for some reason. In order to become more stable, C-14 atoms give off energy by radioactive decay, which is sometimes called disintegration. When a C-14 atom decays, one of the neutrons in the nucleus transforms itself into a proton and a beta particle. The beta particle (nothing more than a high-speed electron) is ejected from the nucleus at the time of the decay (see Figure 5).

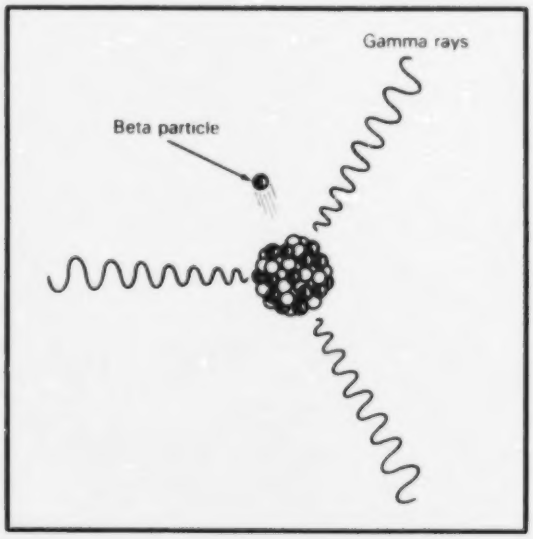

Figure 5 - Radioactive atoms emit particles and gamma rays from the nuclei. Sometimes alpha particles are emitted from certain nuclei. Sometimes beta particles are emitted from certain nuclei without emission of gamma rays. Uranium and its daughter nuclei all together emit alphas, betas, and gammas.

Since the atom now has seven protons but only six electrons, it picks up a free electron from surrounding material to maintain its electrically neutral state. This completes the radioactive decay of the parent atom, carbon-14, to the daughter atom, nitrogen-14 (all atoms that have seven protons in the nucleus are called nitrogen). In this particular instance, the nucleus is now stable, and the daughter nitrogen atom will not undergo further radioactive decay. Many other isotopes in nature undergo beta decay in order to achieve stability in the nucleus.

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Gamma

Some atoms cannot achieve stability by emitting a beta particle. To release some of the excess energy stored in the nucleus, they emit a penetrating bundle of energy that is called a gamma ray or photon. Gamma rays are waves of pure energy that have no weight or mass (see Figure 5). Gamma rays, or photons, are similar to x-rays in their method of interacting with matter. In fact, many of the instruments used to measure gamma rays can also be used to measure x-rays.

Alpha

Some very heavy atoms, such as uranium, cannot release all the energy stored in the nucleus by emitting a beta particle or a gamma ray. Uranium atoms have 92 protons in the nucleus; the three common isotopes of uranium are U-234 (92 protons and 142 neutrons), U-235 (92 protons and 143 neutrons), and U-238 (92 protons and 146 neutrons). All three of these isotopes of uranium undergo radioactive decay by emission of an alpha particle (made of two protons and two neutrons) from the nucleus. In each of these three cases, the daughter nucleus from the uranium decay is unstable and therefore radioactive.

Summary

The three types of radioactive decay are beta, gamma, and alpha. A beta particle is a relatively nonpenetrating high-speed electron. A gamma ray is a bundle of energy with no weight or mass. An alpha particle is a nonpenetrating low-speed package composed of two protons and two neutrons.

MEASUREMENTS ASSOCIATED WITH RADIOACTIVITY AND RADIATION

Activity

An important concept is activity. Activity is a measure of how many radioactive disintegrations occur in a sample over a period of time. The common unit of activity is the curie, abbreviated Ci. If a sample of radioactive material undergoes 37,000,000,000 disintegrations each second, we say it has an activity of 1 curie or 1 Ci. One fresh 800-pound barrel of yellowcake has about 0.2 curie of activity. Small amounts of activity are frequently measured in microcuries (μCi) or disintegrations per second (dps) or disintegrations per minute (dpm). Radioactivity units are discussed more fully in Appendix B.

Half-Life

Another important concept in radioactive decay is half-life. If you measure the number of radioactive decay events in a sample after one half-life, the sample would be only half as radioactive. For example, the half-life of U-238 is 4,600,000,000 years, and the half-life of U-234 is 250,000 years. Not all half-lives are so long. Radium-226 (abbreviated Ra-226), a radioactive daughter of U-238, has a half-life of about 1602 years. Radon-222 (Rn-222), the radioactive daughter of Ra-226, has a half-life of only 3.8 days. Many radioactive isotopes have half-lives of only a few minutes, and some have half-lives that are just a fraction of a second. Almost all of the half-lives have been measured and are listed in nuclear reference books.

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Some people think that the degree of hazard of a radioactive material is based entirely on the half-life. That is not true. The hazard depends mostly on the type of decay (alpha, beta, or gamma), on the energy of the decay particle, and, if it is swallowed or inhaled, on how the body processes the material.

Radiation Dose

You can get a radiation dose from radioactive atoms that are inside your body or outside your body. If the dose is caused by radioactive atoms inside your body, it is called an internal exposure and is controlled by limiting the number of microcuries taken into your body. If the dose is caused by gamma rays or beta particles that came from atoms outside your body, it is called an external exposure and is measured in rems or millirems (there are 1,000 millirems in 1 rem).

The maximum permissible external dose limit for the whole body for a worker at a uranium mill is 1.25 rems each three months. Studies of the external radiation exposure of mill workers have indicated that the average mill worker is exposed to about 0.27 rem, or 270 millirems, each year at work (see Figure 6).

As a point of reference, everyone gets a dose of about 100 millirems each year from natural background radiation. Figure 7 shows the relative contributions of different sources of background radiation, and Figure 8 shows the relative contributions of familiar man-made radiation sources.

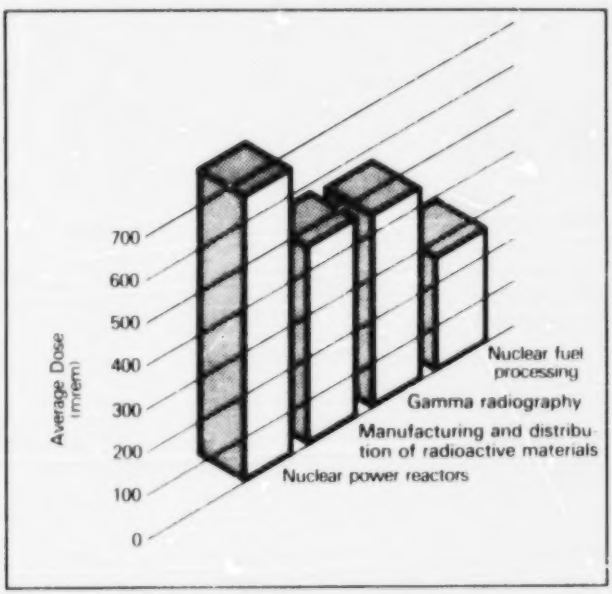

Figure 6 - Average radiation doses to workers. The average dose to a worker at a uranium mill is about the same as that to a worker at nuclear fuel plants. It is less than that to radiographers and other radiation workers in the nuclear industry.

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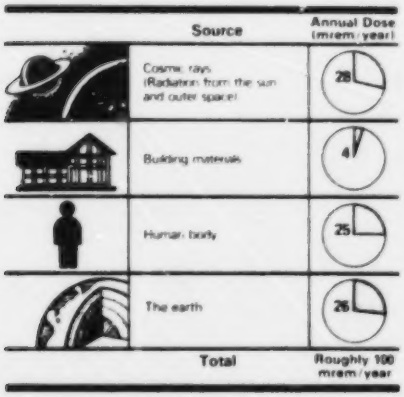

Figure 7 - Relative contributions of background radiation sources to an average person's annual background radiation dose

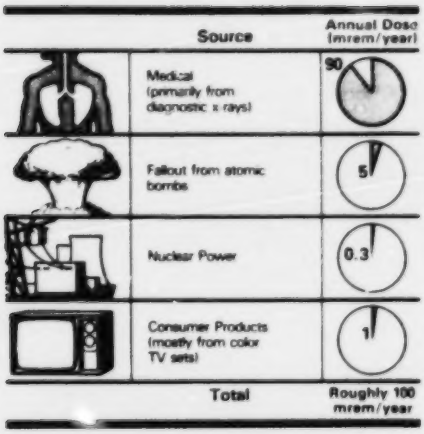

Figure 8 - Relative contributions of man-made radiation sources to the annual man-made radiation dose to an average member of the public

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Airborne Radioactivity

In order to monitor your exposure to radioactive dust that might be inhaled, the concentration of radioactivity in air can be measured by taking an air sample in a work area. Multiplying the concentration by the amount of time you spent in the area gives your exposure. The concentration can be measured either in microcuries per milliliter of air (μCi/ml) or micrograms per cubic meter of air (μg/m^3). (There are 1,000,000 microcuries in 1 curie of radioactivity and 1,000,000 micrograms in 1 gram. The abbreviation for micro is μ). The length of your exposure is usually measured in hours. Therefore, your exposure to airborne uranium would be measured in microcurie-hours per milliliter (μCi-hr/ml) or microgram-hours per cubic meter (μg-hr/m^3).

Radon Gas

Measuring your exposure to radioactive daughters of radon gas in the air presents a special problem, because your dose depends on how quickly the uranium ore is giving off the radon and on how well the work area is ventilated. A special unit, the working level (abbreviated WL), is used to express the amount of radon daughter concentration in an area relative to the permissible level for occupational exposure. Your exposure may then be expressed in working level months (WLM), which is calculated by multiplying the proportion of WL concentration in an area by the number of months you spent in the area. The regulations governing worker exposure limit your exposure to radon daughters to 4 WLM each year.

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CHAPTER 3. THE HAZARDS OF URANIUM

Now that we have discussed radioactive decay and its measurement units, we can look more closely at the uranium decay chain to see why it presents a potential health hazard.

Uranium atoms undergo many radioactive decay processes before reaching a stable daughter isotope of lead. We will see how each decay particle can add to your radiation dose (see Figure 9). We will also discuss the chemical hazards of uranium.

EXTERNAL RADIATION DOSE

The external gamma radiation dose from uranium ore is a minor radiation problem. Remember that gamma radiation is penetrating. This means that the energy given off during a decay can travel through air and through protective clothing and then interact with the atoms in your body. This would be called an external exposure because the radiation came from outside your body. It could cause changes in your body cells. However, not many of the decay events in the uranium decay chain give off gamma rays, so compared to the hazards discussed in the following paragraphs, this is not a major problem.

Many of the radioactive nuclides in the uranium decay chain give off a beta particle during decay. Beta particles are high-speed electrons that are slightly penetrating. The highest energy beta particles from uranium are able to penetrate the protective clothing you wear and the natural surface layer of dead skin to give a radiation dose to the live skin layer just below. When this happens, beta particles are capable of causing changes in these cells.

Alpha particles, although very energetic, do not penetrate the surface layer of skin and do not present any external radiation hazard.

DUST

The principal radiation hazard from uranium and its radioactive daughter nuclides comes from breathing and swallowing the dust. If you are wearing protective clothing and do not work with exposed skin wounds, alpha particles and most beta particles cannot penetrate your skin to give you a radiation dose (see Figures 9b and 9c). However, if the dust and radon daughters are inhaled, they can be deposited directly on the surface of your lung tissue. This would cause a radiation dose to the lungs because the alpha and beta particles would be able to interact directly with the lung tissue (see Figure 9d).

Easily Soluble Yellowcake Dust

If yellowcake has been dried at a low temperature, it forms a compound that can easily dissolve in the fluids in the lungs. The dust from this compound, when deposited in the lung, can cross through the lung tissue and enter the bloodstream. Most of it is then quickly filtered out by the kidneys and gradually excreted in the urine. The radiation dose to the kidneys is not as hazardous as the chemical action of the uranium on the kidney tissue.

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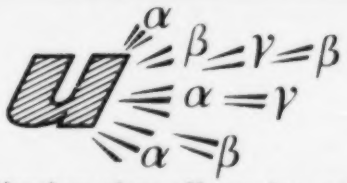
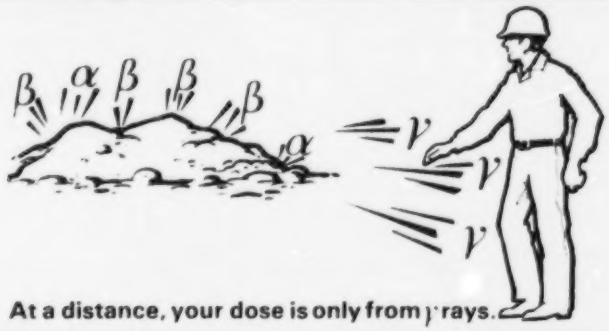
Exposure from Uranium

a.



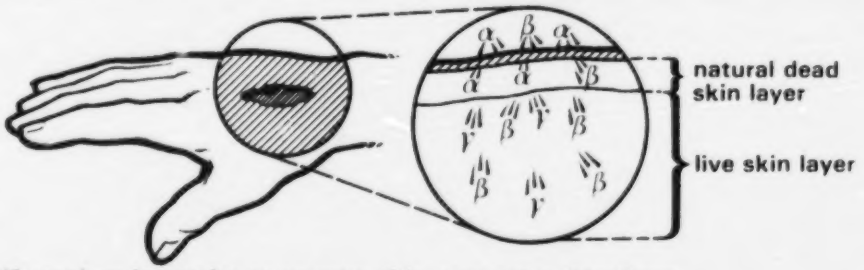
Uranium gives off very low penetration α (alpha) particles, low penetration β (beta) particles, and penetrating γ (gamma) rays

b.



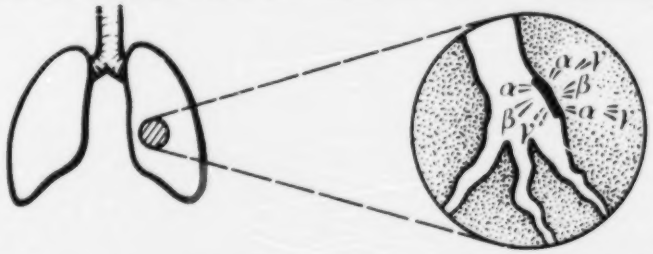
At a distance, your dose is only from γ rays.

c.



If uranium is nearby or on your skin, you get a dose from the β particles and γ rays

d.



If you inhale or swallow uranium, you get dose from all three kinds of radiation.

Figure 9 - Penetration of radiation from uranium sources at different places and different distances from the body

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Since the chemical toxicity of the soluble uranium could cause a health problem long before any radiation effects would be observed, the NRC's maximum permissible concentration of soluble uranium dust in air and water is limited to an amount that is not expected to cause chemical damage to the kidneys.

Less-Soluble Yellowcake Dust

If yellowcake is dried at a high temperature (over 400°C), it forms a less-soluble compound. Inhaled dust from this compound will deposit on the surface of the lungs but will not readily dissolve. The dust is slowly removed to the throat by the normal dust-clearing mechanism, but while it is in the lungs, the alpha and beta particles are giving a radiation dose to the lung tissue. Depending on the size of the dust particles, the dust clearing can take anywhere from days to years. When it is cleared to your throat, the dust is swallowed and then travels through the digestive tract in about 40 hours.

THE NEED FOR CLEANLINESS

The potential effects of breathing or swallowing uranium are the reason that special attention must be given to cleanliness in the mill. Smoking and eating are limited to clean areas of the mill facility to guard against breathing or swallowing the dust. Using work clothing that is left at the mill and laundered there helps to ensure that uranium dust is not carried home where it would unnecessarily expose you and your family. If dust has penetrated through your clothing, it can be removed simply by showering at the end of the work day. A thorough contamination survey or "frisking" of yourself before eating and before you leave the mill at the end of the day will detect dust that may have gotten onto your hair, skin, personal clothing, or shoes.

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CHAPTER 4. SOURCES OF RADIATION EXPOSURE AND DUST IN THE MILL

Uranium, ore dust, radon gas, and radiation are present throughout the mill. However, some areas present a greater health hazard than others. Let's take a quick tour through a typical mill to see where the potential radiation safety problems are. Then we can discuss methods of monitoring those areas to ensure that they do not become health hazards.

RECEIVING PAD

When raw ore is stored on a receiving pad, there is a small gamma exposure rate near the pad. The rate depends on the ore grade and the amount of material present. However, in most cases the uranium on the pad is well shielded by the nonradioactive dirt and rock that it is mixed with, so it does not present a significant health problem.

CRUSHER

When the ore is mixed and crushed, dust is released to the air. Also, the radon gas in the rock is released to the air. Radon gas can mix with the air in the crushing area and be breathed. But as soon as the ground-up ore is mixed with water, the radon gas is once again trapped in the slurry. Most of the radon atoms do not have enough energy to break through the water surface tension. There may be some gamma radiation here, but the ore and the water are still sufficiently thick to shield you from exposure to the beta and alpha particles.

There is also an important potential lung hazard due to silica dust in the air that is created during crushing and grinding operations. Even though it is not radioactive, silica dust can damage lung tissue by causing chronic inflammation and scarring of the lung surface if it is inhaled in large amounts over a long period of time. The same safety measures that you use to reduce your exposure from yellowcake and ore dust will help to reduce the amount of silica you breathe.

LEACHING TANKS

The slurry is piped to the leaching tanks for chemical processing. The radiation that comes from the leaching tanks is probably the smallest contributor to the radiation dose of mill workers because the uranium is in a low concentration and is shielded by the nonradioactive rock, dirt, and water in the tank.

SEPARATION OF SOLIDS AND LIQUIDS

Before the uranium dissolved from the ore in the leaching tanks can be converted back to a concentrated solid by precipitation, the unwanted solids in the leach are removed. The unwanted solids are removed by liquid-solid separation processes, such as countercurrent decantation (CCD) thickeners. These are wet processes that are carried out by remote equipment, so workers are not likely to receive a hazardous exposure from this process. However, airborne activity in the area should be monitored to be sure exposures remain as low as possible.

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PRECIPITATOR

During precipitation and centrifuging, the uranium becomes much more concentrated. If it is completely contained within the pipe runs and equipment, a higher gamma exposure rate may be expected, but there should be no significant alpha or beta exposure. However, any leaks or spills here would increase the chance of contamination until they are cleaned up.

DRYING AREA

In the drying or calcining area, the slurry is heated to drive off the water, leaving behind the dried yellowcake. As with the precipitator, you may expect a gamma exposure rate that is above background, but there should be no alpha or beta exposure from the material inside the dryer. However, the hot gases discharged from the dryer must be washed in "scrubbers" to remove uranium particles. When maintaining or operating the off-gas scrubbing system, you must be careful to keep airborne uranium levels as low as possible.

PULVERIZING AND PACKAGING AREA

After drying, the yellowcake is pulverized so that it can be packaged in 55-gallon steel drums. These two processes, pulverizing and packaging, result in the greatest potential dust hazard in the mill. If pulverizing equipment is not working properly and is not well enclosed, dust can escape and contaminate the room air. Dust that has built up inside the equipment can be released when the equipment is taken apart for repair or maintenance. This dust will be more radioactive than fresh dust because it has had a chance to build up more radioactive daughter atoms.

When the pulverized yellowcake is loaded into drums, a dust cloud will form around the drum if it is not properly enclosed and ventilated. This dust could escape and contaminate the room air.

Drying, pulverizing, and packaging areas have the highest beta radiation levels in the mill because of contamination from accumulated (and aged) yellowcake.

SUMMARY

The pulverizing and packaging areas usually have the highest uranium dust contamination levels in the mill. If the yellowcake was dried at a low temperature, its dust is more soluble in the lungs, and inhaled dust will enter the bloodstream and then be filtered out by the kidneys. If the yellowcake is dried at 400°C or higher, the dust is less soluble and it will deliver more radiation dose to the lung tissue if it is inhaled. Uranium dust represents the greatest hazard to the worker.

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CHAPTER 5. MEASURING TO MONITOR THE HAZARDS

Now that we have taken a quick tour of the entire mill operation, we can look more closely at some of the methods used to monitor radiation levels in the mill. The purpose of monitoring is to detect a small problem so it can be corrected before it becomes a large problem.

GRAB SAMPLES

Levels of uranium ore dust in the grinding area can be measured by taking a grab sample. A sample of the air in the grinding area is taken by pumping air through a filter for about 30 minutes at a flow rate of about 5 liters per minute. The amount of uranium on the filter can be determined by fluorometric analysis or by measuring the amount of radioactivity on the filter. A similar method is used for monitoring yellowcake dust.

Radon-222 gas and its radioactive daughters may be found in the air around ore storage bins and pads, near the crushing and grinding equipment, and in any poorly ventilated rooms. The air concentration is usually measured in working levels, abbreviated WL, and your exposure is then calculated in working level months, abbreviated WLM. (These units are discussed in Appendix B.) The highest working levels of radon gas in mills (usually less than 0.1 WL) are found in the grinding and leaching areas. (As a point of reference, the natural background concentration of radon daughters in an average house is roughly 0.01 WL.) As with uranium ore and yellowcake dust, a sample of the breathing air is pumped through a filter, which is then measured to see how much radioactivity was collected.

THE NEED FOR ACCURATE TIME CARDS

Your employer uses these air sample measurements and worker time cards to calculate the amount of uranium dust and radon daughters that each worker was exposed to. The accuracy of each calculation depends on the accuracy of the information recorded on each time card. Therefore, it is important that you always carefully follow your employer's time card instructions. Stay times and other measurements must be legibly and accurately recorded.

RADIATION SURVEYS

Although they are not the greatest health hazard in mills, beta and gamma radiation levels should also be measured to monitor their contribution to worker dose. Occasionally, areas within a mill might have exposure rates that are high enough to require limited access to the area. Exposure surveys can be made with a radiation survey meter, which provides an immediate reading of an exposure rate.

FILM AND TLD BADGES

Many employers use personal monitors to measure each worker's external radiation exposure. These monitors are called film badges or TLD (for thermoluminescence dosimeter) badges. In order to provide an accurate measure of your exposure, you must follow your employer's instructions for wearing and

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storing your badge. Do not use another person's badge, because there would be no way to know if you or the other person got the exposure reported from the badge. If you lose your badge, tell your supervisor immediately.

Because the badges can be affected by water, chemicals, or heat, tell your supervisor if your badge is accidentally exposed to any of these. Even leaving your badge on a car dashboard in the summer may affect the reading. Therefore, at the end of each day, store your badge in the area specified by your employer.

SURFACE CONTAMINATION SURVEYS

It is possible to contaminate your skin or inhale or ingest radioactive material from the surface contamination (uranium dust) on floors, countertops, handrails, tools, and equipment surfaces. Therefore, surface contamination surveys are made in areas where radioactive dust may accumulate. These surveys are made by simply wiping the area with a piece of paper or fabric and then measuring the amount of radioactivity on the sample. The recommended limit for removable alpha contamination in uranium work areas is 0.001 $\mu Ci/cm^2$ (equal to 220,000 dpm/100 cm^2). This amount of yellowcake dust is readily visible on a surface that has been painted a contrasting color. The recommended limit for removable contamination in nonuranium work areas and on equipment or other items that will be released for unrestricted use is 1,000 dpm/100 cm^2.

FRISKING

Surveys of your clothing provide a good backup check to ensure that you have not become contaminated and that you will not carry contamination to your home and family. Before leaving the mill area, you should monitor your skin and clothing with an alpha survey instrument. The survey must be done with the detector held close to the skin or clothing. It must be done slowly to allow the instrument time to detect and indicate the average contamination. If the instrument is moved over the surface too quickly, it will indicate a lower contamination level than is actually present. If your skin contamination level is higher than 1,000 dpm of alpha contamination per 100 cm^2 (about 4 inches by 4 inches square), you should shower and then survey yourself again. Shoe soles should also be carefully monitored and thoroughly brushed or washed if they are contaminated.

Any material or equipment that is removed from the mill must also be carefully surveyed to be sure it is not contaminated. There are special surveys that must be made by the safety staff before things can be released.

BIOASSAYS

As a final test to determine whether or not all these measures have been effective in keeping workers' intake of uranium below acceptable levels, mill licensees perform bioassay measurements. There are two types of bioassay measurements--they are called urinalysis and in vivo measurement.

Urinalysis

The urinalysis test measures the amount of uranium in your urine. Urine samples are usually collected biweekly or monthly. In order to ensure that the

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sample is not accidentally contaminated by uranium, you should wash your hands well before collecting the sample. Each urine sample is analyzed in the laboratory to determine the micrograms of uranium per liter of urine. If the concentration is less than the action level set by the licensee, this indicates that you are not inhaling hazardous air concentrations of soluble uranium. If the measurement exceeds the action level, the safety staff will investigate the cause and correct it. The safety staff will also follow up and watch the worker to determine whether medical care is needed.

In Vivo Measurement

The in vivo test measures the amount of radioactivity in your lungs. Because the detector that is used for this measurement is so sensitive, you and the detector are placed in a shielded box during the measurement. This allows the detector to measure only the radioactive material in your lungs, without interference from natural background radiation. If the amount of uranium in your lungs is less than 9 nanocuries (0.009 μCi), there is no need for any corrective action in the mill or in work procedures. In vivo measurements are usually made about once each year. For an accurate in vivo measurement, it is especially important that you shower beforehand and wear clean clothes. This will ensure that contamination on your skin does not contribute to the measurement of the amount of activity in your lungs.

SUMMARY

All the measurements described above are needed to determine whether worker exposures are being properly controlled. Therefore, each worker must carefully follow all the instructions given when taking a sample or making a survey to ensure that the measurement will be accurate. Logbook and timecard entries must be legible. It is very important that samples not be spiked by workers to "test" the safety office.

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CHAPTER 6. SAFETY MEASURES FOR WORKING IN A URANIUM MILL

Almost all radiation safety measures in a uranium mill are based on cleanliness. The measures are designed to ensure that you do not get ore dust or yellowcake on your skin or breathe or swallow it. Strict adherence to good housekeeping will reduce the number of pathways by which you can be contaminated with this material. Strict adherence to personal cleanliness will help to ensure that, if your skin or clothing does become contaminated, the contamination will be removed promptly.

CLOTHING

To minimize the possibility of contaminating your skin, you should wear clothing that can be completely buttoned or zipped shut when you put it on. Gloves will help eliminate contamination on your hands. If the gloves are made of heavy rubber or leather, they will also reduce the dose to your hands from external beta radiation in the yellowcake drying and packaging area. Safety glasses will protect your eyes from flying objects and will help to reduce the radiation exposure to your eyes. Pant legs should fit tightly over boot tops, and gloves should fit tightly over shirt or jacket sleeves. A hat or hood will reduce the amount of dust in your hair.

If you are properly dressed, your clothing will prevent contamination from reaching your skin. To avoid becoming contaminated by your clothing, it should be cleaned regularly. Boots should be thoroughly brushed or washed daily before removing your work clothes. Coveralls, gloves, and hats should be washed weekly and whenever there is any visible yellowcake dust on them.

WASHING

Since any contamination on your body may easily be ingested, you should wash your face and hands before eating, drinking, or smoking. Shower and wash your hair each day before leaving the mill. These measures are especially important if you have been working in the yellowcake area.

RESPIRATORS

Some mills provide respirators for use in dusty areas such as around jaw crushers, sampling conveyors, bins for dry crushed ore, and yellowcake drying and packaging equipment. Respirators are also frequently used during repair and maintenance work if dust or mist will be created. The most commonly used respirators are the half-face, full-face, and hood types. These all use filters to remove the dust from the air you breathe. (See Figure 10 for how to check a half-face respirator before use.)

If you use a respirator, some basic steps must be taken to ensure that it will help reduce the amount of dust you inhale. The steps will be explained and demonstrated by your employer. Check to be sure the respirator you use has been cleaned and serviced according to your employer's operating procedures. In order to be effective, the respirator must be tightly fitted over clean-shaven skin. The harness straps must be on your head, not over your hard hat. Be sure you can breathe comfortably before going into the work area.

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A. Check headbands, fasteners, adjusters, cartridge holders, and cartridges for breaks, tears, and distortion.

B. Check the facepiece and valves for breaks, tears, distortion, and distortion.

C. First check the fit by gently covering the exhalation valve with your palm and exhaling. The facepiece should bulge out from your face before it leaks out around the edge.

D. Then check the fit by gently covering the cartridges and inhaling. The facepiece should collapse against your face rather than leaking around the edge.

Figure 10. How to check a respirator.

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If your employer uses the respirator "protection factor" to estimate what fraction of the dust in the room air was removed by the respirator in order to calculate your exposure, NRC regulations require that your employer have a quality assurance program to ensure that each respirator is used properly. The program must include worker training, air sampling and bioassays, individual fitting and testing, respirator maintenance, and an annual determination by a physician that each worker is physically able to use a respirator.

RADIATION SAFETY SIGNS

If the radiation level in an area is so high that a worker could be exposed to 5 millirems in an hour or 100 millirems in five days, the area must be posted with a "Radiation Area" sign.

If the radiation level in an area is so high that a worker could be exposed to 100 millirems in an hour, the area must be posted with a "Caution, High Radiation Area" sign. Levels may be this high near tank walls or pipes if radium has plated out of solution because of the chemistry used at the mill. In addition to being posted with signs, these areas are usually roped off and special permission is required to enter them.

If more than 10 millicuries of natural uranium is stored in an area, the area must be posted with a "Caution, Radioactive Materials" sign. Many licensees simply post each entrance to the mill.

If the amount of radioactivity in the air in a room or area (averaged over the number of hours each week someone is there) exceeds one-fourth of the maximum permissible concentration, the area must be posted with a "Caution, Airborne Radioactivity Area" sign.

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CHAPTER 7. RADIATION PROTECTION REGULATIONS

In some States, NRC regulations govern the radiation hazards caused by the milling of uranium. In the other States, the State government has established similar regulations as part of an agreement with the NRC. They are called Agreement States. The Mine Safety and Health Administration also has regulations governing exposure to radon daughters that are compatible with the NRC regulations. The following information is based on the NRC regulations that apply in non-Agreement States.

NRC REGULATIONS

The NRC regulations governing work with radioactive material are in Title 10 of the Code of Federal Regulations. The two parts that most directly affect you as a worker are Part 19, "Notices, Instructions, and Reports to Workers; Inspections," and Part 20, "Standards for Protection Against Radiation." (Your radiation safety officer will have copies that you may read. You may order a single free copy of each part of the regulations by writing to the Division of Technical Information and Document Control, Distribution Services Branch, U.S. Nuclear Regulatory Commission, Washington, DC 20555.)

Part 19 requires each licensee to post a copy of both Part 19 and Part 20, a copy of its NRC license, and a copy of any notice of violation. (If this is impractical, the licensee may simply post a notice that tells where these documents may be examined.) It also requires each licensee to post a copy of NRC Form 3. This form describes your rights as a radiation worker and your employer's responsibilities. If you wish to register complaints or concerns about radiological working conditions or other matters regarding compliance with NRC rules and regulations, the NRC Regional Offices will accept collect telephone calls. NRC Form 3 has the address and telephone number of each NRC Regional Office.

Part 19 also requires that your employer instruct you in radiation safety in general, in the specific equipment and procedures used to minimize your exposure in your work area, in the applicable provisions of the regulations and the license that was issued by the NRC, in your responsibility to report unsafe conditions to your employer, and in emergency procedures. You may request a report of your radiation exposure record annually and when your employment ends. If you think your employer is violating the regulations o conditions of the license, you can contact the NRC Regional Office and ask for an inspection. You may also discuss radiation safety matters privately with an NRC inspector during an inspection.

Part 20 establishes limits for radiation exposure to workers and the general public, and it lists permissible levels of airborne contamination. It also requires that your employer post the radiation safety signs discussed in the previous chapter, establish monitoring procedures, and keep records of surveys and employee exposures.

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REGULATORY GUIDES

The NRC publishes regulatory guides that provide additional guidance on radiation effects and safety measures. There are several regulatory guides that may be of interest:

Regulatory Guide 8.10, Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable

Regulatory Guide 8.11, Applications of Bioassay for Uranium

Regulatory Guide 8.13, Instruction Concerning Prenatal Radiation Exposure

Regulatory Guide 8.15, Acceptable Programs for Respiratory Protection

Regulatory Guide 8.22, Bioassay at Uranium Mills

Regulatory Guide 8.29, Instruction Concerning Risks from Occupational Radiation Exposure

Regulatory Guide 8.30, Health Physics Surveys in Uranium Mills

Regulatory Guide 8.31, Information Relevant to Ensuring that Occupational Radiation Exposures at Uranium Mills Will Be As Low As Is Reasonably Achievable

Your radiation safety officer should have a copy of each of these guides for you to look at. You may order copies of each guide by writing to the Superintendent of Documents, U.S. Government Printing Office, Post Office Box 37082, Washington, DC 20013-7082.

GENERAL REFERENCE BOOKS

There are many textbooks and articles that provide detailed information on the science and practice of radiation protection. The books listed here provide more information on radiation protection for those who are interested or who have responsibility for radiation safety.

H. Cember, Introduction to Health Physics, 2nd Edition, Pergamon Press, New York, 1983.

R. L. Kathren, Radiation Protection, Adam Hilger Ltd., Bristol, England and Boston, 1985.

J. Shapiro, Radiation Protection, a Guide for Scientists and Physicians, 2nd Edition, Harvard University Press, Cambridge, MA, 1981.

B. Shleien and M. S. Terpilak, Editors, The Health Physics and Radiological Health Handbook, Nucleon Lectern Associates, Inc., Olney, MD, 1984.

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APPENDIX A

SCIENTIFIC NOTATION

(This appendix is provided for those who are interested in the calculations involved with measurements. It is not intended to be a required part of safety training.)

In many types of scientific work, there are measurements that are very large or very small. Without some type of shorthand notation, it would be very easy to make an arithmetic mistake by misplacing the decimal point in a calculation. The use of scientific notation helps to avoid this problem.

LARGE NUMBERS

In scientific notation, numbers are written as a number multiplied by a power of ten. For example, the number 160,000 is equal to the product of $1.6 \times 10 \times 10 \times 10 \times 10 \times 10$. This can be rewritten in shorthand form as 1.6×10^5. The "5" indicates that you must multiply 1.6 by 10 five times in order to express the original number. We could also write 160,000 as $160 \times 10 \times 10 \times 10$ or 160×10^3. Other forms would be 0.16×10^6 or $0.16 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$. All three versions, 1.6×10^5, 160×10^3, and 0.16×10^6, are correct examples of scientific notation.

Notice that you simply count the number of spaces that you have moved the decimal point to the left to see how many multiplications by 10 there are.

SMALL NUMBERS

In addition to dealing with large numbers, we also sometimes have to deal with very small numbers. For example, 0.0000045 is the same as $\frac{4.5}{10\times10\times10\times10\times10\times10}$. Since there are six factors of 10 to divide by, this number could be rewritten as 4.5×10^{-6}. It could also be written $\frac{45}{10\times10\times10\times10\times10\times10\times10}$ or $\frac{0.0045}{10\times10\times10}$. These two expressions would be written in scientific notation as 45×10^{-7} and 0.0045×10^{-3}.

For decimal fractions, simply count the number of spaces that you have moved the decimal point to the right when converting to scientific notation.

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PROBLEMS

$160{,}000 = \underline{1.6} \times 10^{5}$

$160{,}000 = \_\_\_\_\_ \times 10^{3}$

$160{,}000 = \_\_\_\_\_ \times 10^{6}$

$54{,}000 = \_\_\_\_\_ \times 10^{3}$

$85{,}000{,}000 = \_\_\_\_\_ \times 10^{6}$

$2{,}200{,}000{,}000{,}000 = 2.2 \times 10^{12}$

$340{,}000 = 3.4 \times 10^{\text{—}}$

$99{,}000{,}000 = 99{,}000 \times 10^{\text{—}}$

$47{,}000 = 4.7 \times 10^{\text{—}}$

$76{,}000{,}000 = 7.6 \times 10^{\text{—}}$

$0.0023 = \underline{2.3} \times 10^{-3}$

$0.0000092 = \_\_\_\_\_ \times 10^{-6}$

$0.00000000045 = \_\_\_\_\_ \times 10^{-10}$

$0.007 = \_\_\_\_\_ \times 10^{-3}$

$0.0000069 = \_\_\_\_\_ \times 10^{-7}$

$0.87 = 870 \times 10^{-3}$

$0.094 = 0.94 \times 10^{\text{—}}$

$0.000003 = 0.3 \times 10^{\text{—}}$

$0.00057 = 5.7 \times 10^{\text{—}}$

$0.00042 = 42 \times 10^{\text{—}}$

$7.2 \times 10^{5} = \underline{720{,}000}$

$65 \times 10^{6} = \_\_\_\_\_$

$4.4 \times 10^{8} \_\_\_\_\_$

$11 \times 10^{9} = \_\_\_\_\_$

$26 \times 10^{6} = \_\_\_\_\_$

$1.3 \times 10^{7} = \_\_\_\_\_$

$54 \times 10^{12} = \_\_\_\_\_$

$8 \times 10^{4} = \_\_\_\_\_$

$97 \times 10^{3} = \_\_\_\_\_$

$39 \times 10^{2} = \_\_\_\_\_$

$48 \times 10^{-3} = \underline{0.048}$

$5.2 \times 10^{-11} = \_\_\_\_\_$

$81 \times 10^{-4} = \_\_\_\_\_$

$37 \times 10^{-6} = \_\_\_\_\_$

$29 \times 10^{-5} = \_\_\_\_\_$

$16 \times 10^{-8} = \_\_\_\_\_$

$0.72 \times 10^{-6} = \_\_\_\_\_$

$0.094 \times 10^{-3} = \_\_\_\_\_$

$11 \times 10^{-6} = \_\_\_\_\_$

$0.003 \times 10^{-4} = \_\_\_\_\_$

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MULTIPLICATION

Scientific notation can be used to keep track of the decimal point when doing mathematics problems with very large or very small numbers. To multiply 3,000 x 160,000, we first rewrite the problem as $3 \times 10^3 \times 16 \times 10^4$. Then reorder the factors in the problem by listing all the decimal numbers first, and then listing the powers of 10. In this case, we have $3 \times 16 \times 10^3 \times 10^4$. The 3 x 16 gives 48. To multiply the powers of ten, simply add the exponents. The final answer is 48×10^7. Check this by hand multiplication or with a calculator. It might be more convenient in some cases to write this as 4.8×10^8 or 480×10^6. All three are equally acceptable mathematically.

When recording numbers in log books, the supervisor will usually determine the format of the number to be entered. If all entries were to be made as a multiple of 10^6, this number would be written in the log book as 480×10^6.

To multiply 3500 by 0.0001, first convert the numbers to scientific notation. This results in $3.5 \times 10^3 \times 1 \times 10^{-4}$. Then reorder the numbers to $3.5 \times 1 \times 10^3 \times 10^{-4}$. Now multiply the decimal numbers and add the powers of 10. $3.5 \times 1 = 3.5$. $10^3 \times 10^{-4} = 10^{3+(-4)} = 10^{-1}$. The final answer is 3.5×10^{-1}. This could also be written as 0.35 or 35×10^{-2}. (Note: Since $10^2 = 100$, $10^1 = 10$, $10^{-1} = .1$, and $10^{-2} = .01$, remember that $10^0 = 1$ when doing calculations.)

DIVISION

Since you add powers of 10 to multiply, you subtract powers of 10 to divide. For example, $24 \times 10^5 \div 4 \times 10^3$ should first be rewritten as

$$\frac{24 \times 10^5}{4 \times 10^3}$$

$24 \div 4 = 6$. $10^5 \div 10^3 = 10^{5-3}$, or 10^2. Therefore, the answer would be written 6×10^2. For $12 \times 10^{-8} \div 2 \times 10^5$, the steps would be as follows:

$$\frac{12 \times 10^{-8}}{2 \times 10^5}$$

$$= 6 \times 10^{-8-5}$$

$$= 6 \times 10^{-13}$$

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PROBLEMS

$1.6 \times 10^5 \times 65 \times 10^6 =$	1.0×10^{13}	$0.72 \times 10^{-7} \div 48 \times 10^{-4} =$	1.5×10^{-5}
$54 \times 10^3 \times 48 \times 10^{-4} =$		$1.6 \times 10^5 \div 29 \times 10^{-5} =$	
$870 \times 10^{-3} \times 29 \times 10^{-5} =$		$54 \times 10^3 \div 65 \times 10^6 =$	
$3 \times 10^{-6} \times 4.4 \times 10^8 =$		$3 \times 10^{-6} \div 37 \times 10^4 =$	
$7.6 \times 10^5 \times 0.72 \times 10^8 =$		$1.3 \times 10^7 \div 9.4 \times 10^6 =$	
$37 \times 10^3 \times 16 \times 10^{-8} =$		$0.72 \times 10^8 \div 52 \times 10^8 =$	
$9.4 \times 10^{-6} \times 57 \times 10^3 =$		$37 \times 10^3 \div 7.6 \times 10^5 =$	
$42 \times 10^5 \times 54 \times 10^{12} =$		$4 \times 10^{12} \div 4.3 \times 10^{12} =$	
$99 \times 10^6 \times 1.3 \times 10^7 =$		$48 \times 10^{-4} \div 7.2 \times 10^8 =$	
$0.72 \times 10^{-6} \times 34 \times 10^4 =$		$16 \times 10^{-8} \div 45 \times 10^4 =$	

In many types of problems, both multiplication and division are required. Let's assume we have taken an air sample and have to calculate the amount of uranium ore dust in the air. The pump that was used to draw the air sample was pumping 30 liters per minute, or 30,000 milliliters per minute. Another way to write this is 3×10^4 ml/min. We ran the pump for 60 minutes. The sample filter on the pump collected 36×10^{-6} µCi of ore dust. (This problem assumes that every bit of uranium in the sampled air was collected on the filter.) First we can calculate the total amount of air that was sampled.

$3 \times 10^4 \frac{\text{ml}}{\text{min}} \times 60 \text{ min} = 3 \times 60 \times 10^4$, or 180×10^4, or 1.8×10^6 ml of air.

To calculate the concentration, we must divide the total activity by the total air volume, or $\frac{36 \times 10^{-6} \text{ µCi}}{1.8 \times 10^6 \text{ ml}}$. Since we add exponents when we multiply, we subtract exponents when we divide. We now have $\frac{36}{1.8} \times 10^{-6-6}$ or 20×10^{-12} µCi/ml. This could be rewritten as 2×10^{-11} or $.2 \times 10^{-10}$ µCi/ml.

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APPENDIX B

UNITS OF MEASUREMENT

(This appendix is provided for those who are interested in units of measurement and measurement systems. It is not intended to be a required part of safety training.)

Measurement systems have been designed so that people can talk about quantities. Without them, it would be difficult to describe amounts of length, volume, weight, or time.

There are two commonly used measurement systems in the United States. One of them is the American system that actually originated in England centuries ago. It is the common system that uses inches, feet, yards, and miles to measure distance; quarts and gallons to measure capacity; and seconds, minutes, and hours to measure time.

The other system is called the metric system. It is used throughout most of the world in everyday commerce. It is also used by most scientists in the United States.

UNITS OF LENGTH

In the metric system, the unit of length is the meter (m). One meter is slightly longer than a yard. When a meter is inconvenient to use for a measurement of a length or distance that is small, you can use a centimeter (cm), which is one-hundredth of a meter. A centimeter is about 3/8 inch, and 2½ centimeters is about the same distance as 1 inch. For large distances that would be measured in miles, kilometers (km) are used. A kilometer is the same as 1,000 meters. That is about the same distance as 5/8 mile.

UNITS OF CAPACITY

In the metric system, the unit of capacity is the liter (L or l). If you made a box that was 10 centimeters (about 4 inches) long on each edge, it would have a capacity of 1 liter. A liter is slightly larger than a quart. If the liter is an inconvenient unit to use for a measure, you can use a milliliter (ml). A milliliter is one-thousandth of a liter. It is the same volume as a cubic centimeter (cc).

UNITS OF WEIGHT

In the metric system, the unit of weight is the kilogram (kg). A liter of water weighs 1 kilogram, about the same as 2 pounds. If the kilogram is too large a unit, you can measure a weight in grams (g). A gram is one-thousandth of a kilogram. One ounce is about the same as 30 grams. Sometimes even the gram is too large a unit to use for a measurement. In that case you can express a weight in micrograms (μg). A microgram is a millionth of a gram.

UNITS OF TIME

The metric system uses the same time units that are used in the American system of measurement. These are the second, minute, and hour.

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UNITS OF RADIOACTIVITY

Both systems use the same two units for measuring radioactivity. The older and more common unit is the curie (Ci). If a sample of radioactive material undergoes 37,000,000,000 disintegrations per second (dps), it has an activity of 1 curie. Commonly used submultiples of the curie are the millicurie (abbreviated mCi and equal to 37,000,000 dps), the microcurie (abbreviated μCi and equal to 37,000 dps), the nanocurie (abbreviated nCi and equal to 37 dps), and the picocurie (abbreviated pCi and equal to 0.037 dps, or about 2 disintegrations every minute).

The newer measure of radioactivity is the becquerel (Bq). If a sample of radioactive material undergoes one disintegration each second, it has an activity of 1 becquerel. A sample of radioactive material that exhibited an activity of 1 nCi, or 37 dps, would be said to have an activity of 37 Bq. This is a very tiny amount of radioactivity. Larger units are the kilobecquerel (1,000 dps), the megabecquerel (1,000,000 dps), the gigabecquerel (1 thousand million dps), and the terabecquerel (1 million million dps).

A common measurement unit for the amount of ore dust or yellowcake in the air is micrograms per cubic meter ($\mu g/m^3$). It is also possible to make a measurement of radioactivity per volume of air to describe the amount of ore dust or yellowcake in the air. A common measurement unit for this is microcuries per milliliter (μCi/ml).

MEASURING WORKER EXPOSURE

Calculations are often made to measure worker exposure to airborne radioactive material. The maximum permissible concentration (MPC) for soluble yellowcake is 1×10^{-10} microcurie per milliliter of air; for uranium ore dust, the MPC is 5×10^{-11} microcurie per milliliter of air. (MPC does not mean it is against the law to have higher concentrations in the air. However, if the concentrations are higher, your employer must limit the amount of time you spend in the area.) The measure of your exposure is the product of airborne radioactive material concentration (measured in MPCs) multiplied by the amount of time you were in the area (measured in hours). The quarterly exposure limit for each worker is 520 MPC-hours.

Let's assume you start the quarter with your 520 MPC-hour work bank. The first week you worked in a yellowcake room for 30 hours, and an air sample showed that the level of soluble yellowcake in the room air was 2×10^{-11} microcurie per milliliter. Since the MPC for yellowcake dust is 1×10^{-10} microcurie per milliliter, this is 0.2 MPC ($2 \times 10^{-11} \div 1 \times 10^{-10} = 0.2$). The second week you worked in a different yellowcake room for 20 hours, and the concentration was 3×10^{-11} microcurie per milliliter, or 0.3 MPC. The third week you worked in the crushing area where ore dust was present. The MPC for ore dust is 5×10^{-11} microcurie per milliliter. You worked in that area for 35 hours, and the concentration was 1×10^{-11} microcurie per milliliter, or 0.2 MPC. (We assume that, in each case, the remainder of the work week was spent in areas where there was no air contamination.) Now we can calculate your MPC hours for the first 3 weeks of the quarter.

The first week, your exposure was 30 hours x 0.2 MPC = 6 MPC-hours. You started the quarter with a bank of 520 MPC-hours. At the end of the week, you

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have used 6 MPC-hours, so the balance of your exposure for the quarter cannot exceed 520 - 6 = 514 MPC-hours. The second week, your exposure was 20 hours x 0.3 MPC = 6 MPC-hours. Now your balance is 514 - 6 = 508 MPC-hours. The third week, your exposure was 35 hours x 0.2 MPC = 7 MPC-hours, leaving a balance of 501 MPC-hours. This method, although somewhat complicated, tends to give proper balance to exposures at different concentrations for different periods of time so that, over a year, each worker's accumulated exposure can be recorded. Notice that the accurate calculation of your exposure depends on knowing the exact amount of time you spent in each work area.

In addition to limiting your quarterly intake of material, the regulations require that, if you exceed 40 MPC-hours in a week, your employer must take whatever actions are necessary to prevent a recurrence. Your employer is also required to use process and engineering controls, when practicable, to keep air concentrations below 25% of the MPC.

Some companies prefer to monitor worker exposure to dust by measuring the weight of dust in the air. It is usually measured in terms of micrograms per cubic meter ($\mu g/m^3$). The exposure calculations would be done in the same manner, but the exposure result would be expressed in microgram-hours per cubic meter (μg-hours/m^3).

Radon gas in the air presents a special measurement problem because it decays into radioactive daughter atoms. The concentration of the radioactive daughters in the air depends on the amount of fresh air that is supplied to the work area. Therefore, a special unit called the working level (abbreviated WL) has been defined. It is based on the number of alpha particle disintegrations in a liter of air. Another unit based on the working level is the working level month (abbreviated WLM). The regulations governing worker exposure limit your exposure to radon daughters to 4 working level months each year. Since there are 170 work hours each month, you could express this limit as 680 working level hours each year.

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This report provides information for uranium mill workers to help them understand the radiation safety aspects of working with uranium as it is processed from ore to yellowcake at the mills. The report is designed to supplement the radiation safety training provided by uranium mills to their workers. It is written in an easily readable style so that new employees with no previous experience working with uranium or radiation can obtain a basic understanding of the nature of radiation and the particular safety requirements of working with uranium. The report should be helpful to mill operators by providing training material to support their radiation safety training programs.

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